22nd Asia and South Pacific Design Automation Conference (ASP-DAC 2017)

Special Session 4S: Invited Talk

Design Considerations and Clinical Applications of Closed-Loop Neural Disorder Control SoCs

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Outline

I. Introduction: Parkinson's Disease and epilepsy

II. System Architecture and Design Considerations

III. Experimental Results

IV. Future Development

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Outline

I. **Introduction**

II. System Architecture and Design Consideration

III. Experimental Results

IV. Future Development

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I. Introduction

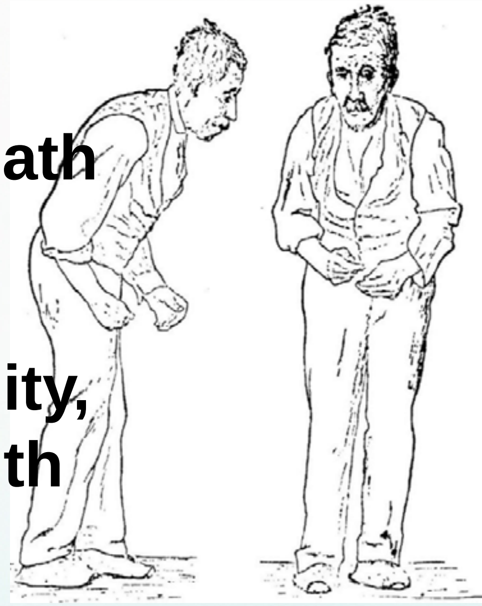
Parkinson’s Disease and Epilepsy

- Parkinson’s disease and epilepsy are common neurological disorders.

  PD: 1%~2% of the people older than 65.

  Epilepsy: 70 million people worldwide.

- Parkinson's disease is caused by the death of dopamine-generating cells in the substantia nigra (SN). The movement-related symptoms include shaking, rigidity, slowness of movement, and difficulty with walking and gait.



I. Introduction

Parkinson's Disease and Epilepsy

- **Epileptic seizures are caused by sudden excessive electrical discharges in a group of cortical neurons.**

Seizure Onset

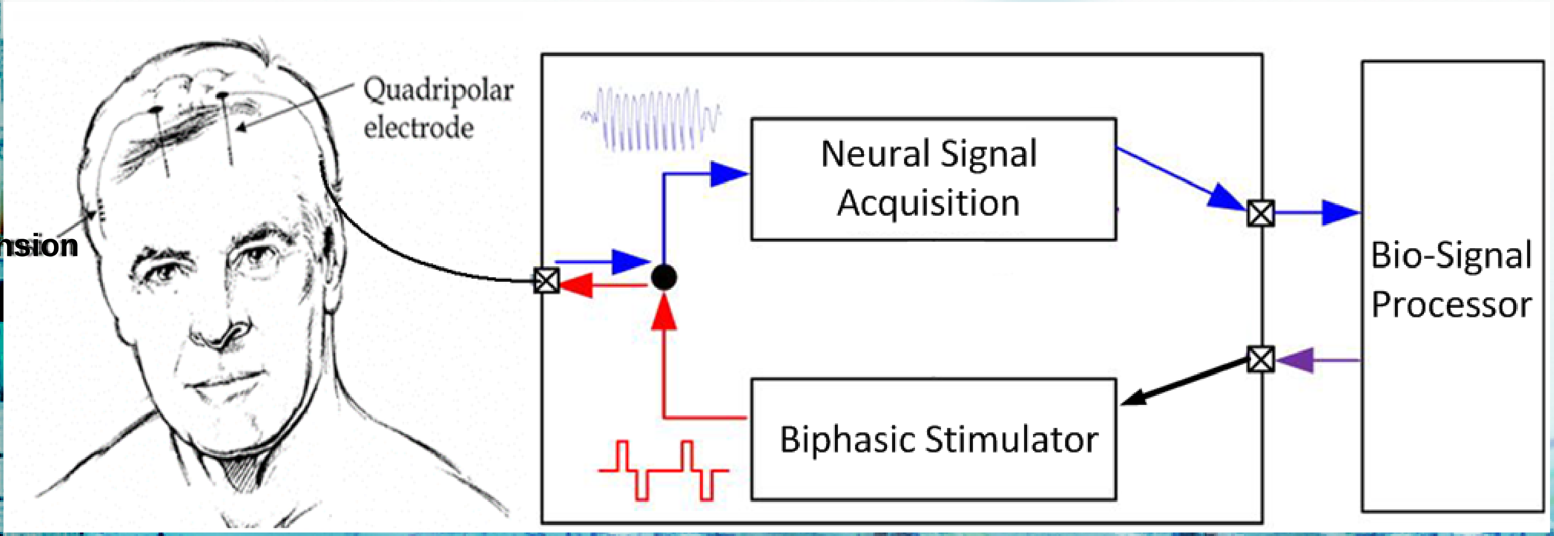
Courtesy of Prof. Dr. Yue-Loong Hsin

I. Introduction

Open-Loop VS Closed-Loop Neuromodulation

- Open-loop DBS neuromodulation system leads to higher power dissipation, frequent battery replacement, and overstimulation symptoms.
- The closed-loop DBS system composed of neural signal acquisition, bio-signal processor, and biphasic stimulator.

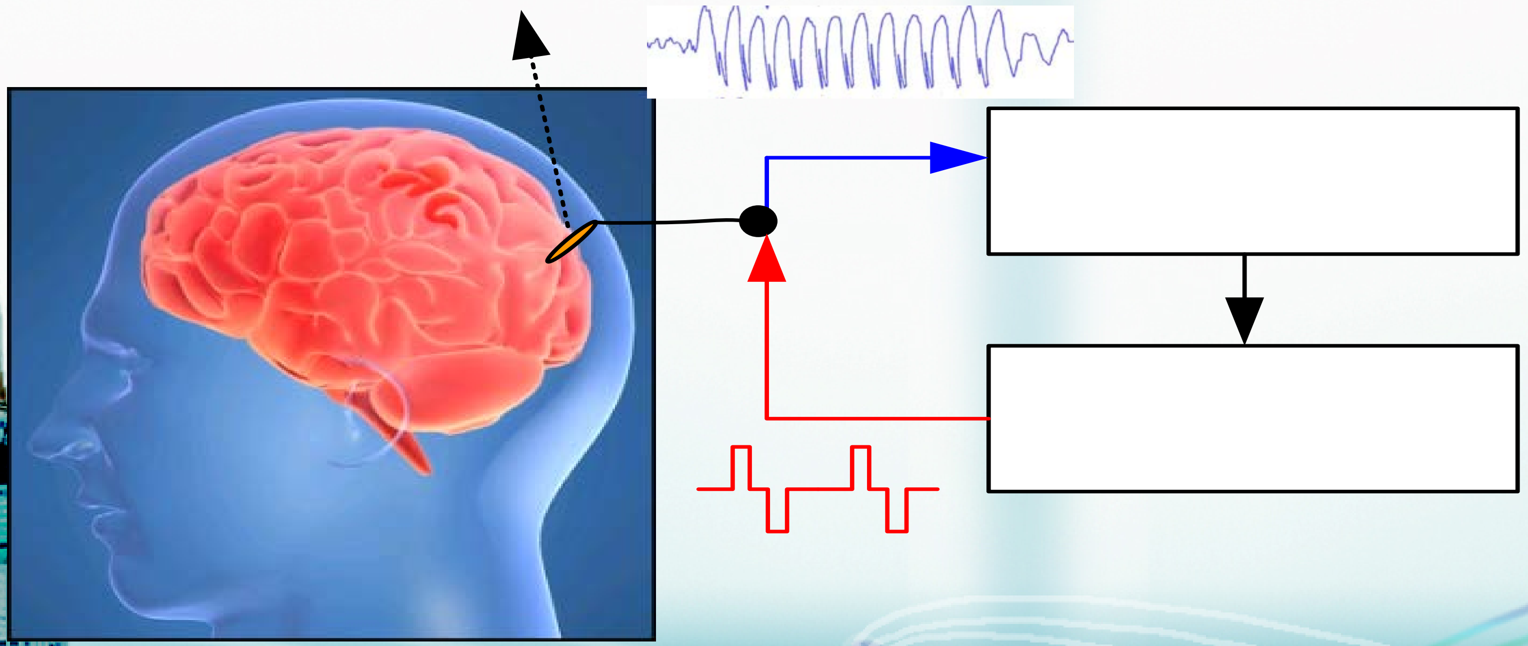
Extension



I. Introduction

Open-Loop VS Closed-Loop Neuromodulation

- The closed-loop epileptic seizure control system



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II. System Architecture and Design Considerations

A. Closed-loop PD DBS system for pre-implant Evaluation

II. System Architecture and Design Considerations

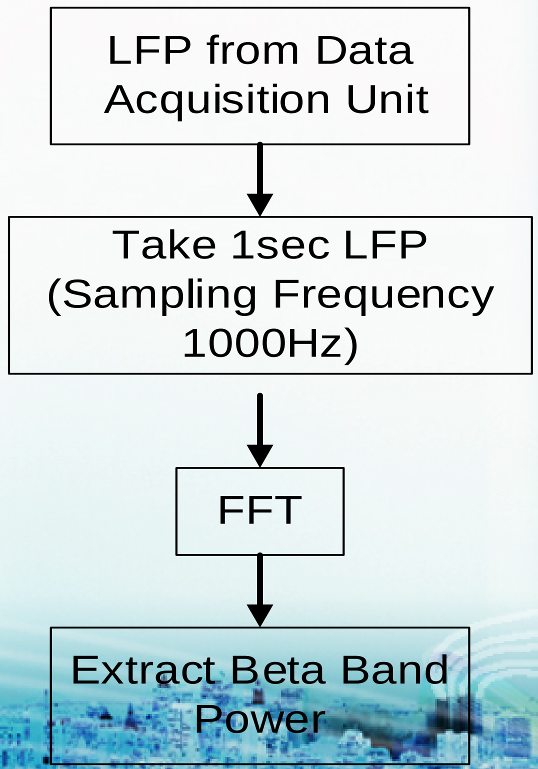
A. Closed-loop PD DBS system for pre-implant Evaluation

- The Local Field Potential (LFP) is sensed and digitized by the bio-signal acquisition unit using TI ADS1299.
- The digitized LFP data are then processed by a processor in the NI platform to calculate the β-band power.
- Once the β-band power exceeds the preset threshold, the stimulator using NI 9269 generates the patient-specific 0.1-3V biphasic voltage stimulations.
- The closed-loop DBS system meets the IEC 60601-1 for medical electrical equipment.

II. System Architecture and Design Considerations

A. Closed-loop PD DBS system for pre-implant Evaluation

- The β-band power of LFP is an efficient bio-maker for closed-loop PD DBS system.
- The extraction of β-band power spectral density is implemented by a decimation-in-frequency FFT algorithm in the NI platform.



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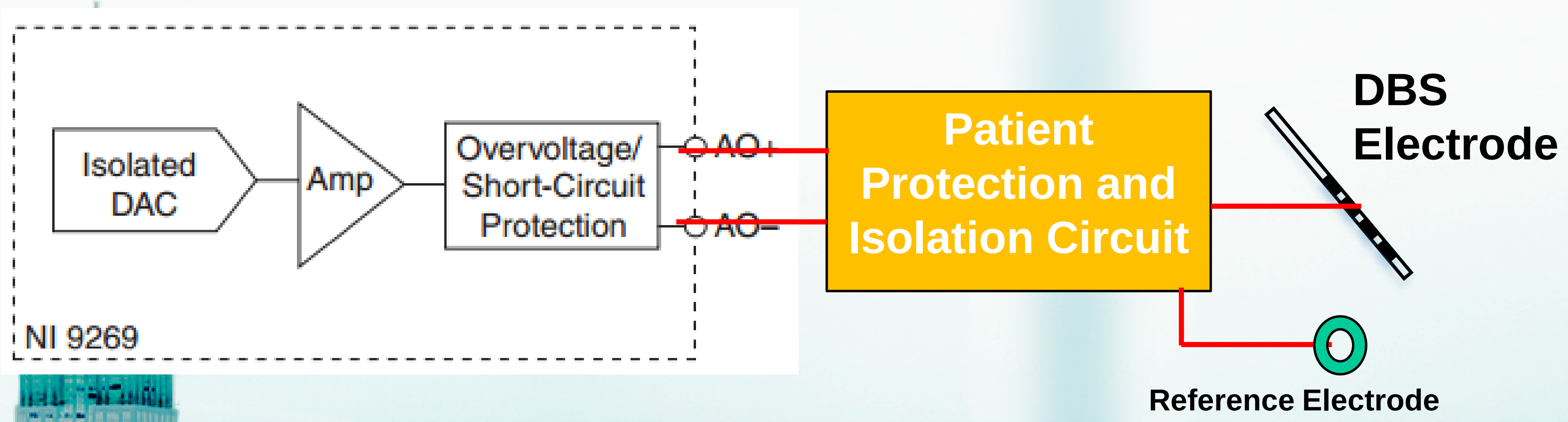
II. System Architecture and Design Considerations

A. Closed-loop PD DBS system for pre-implant Evaluation

Specifications of the Stimulator NI 9269:

- 5~130Hz programmable stimulation frequency
- 0~3v programmable stimulation voltage
- Stimulation latency <0.5sec



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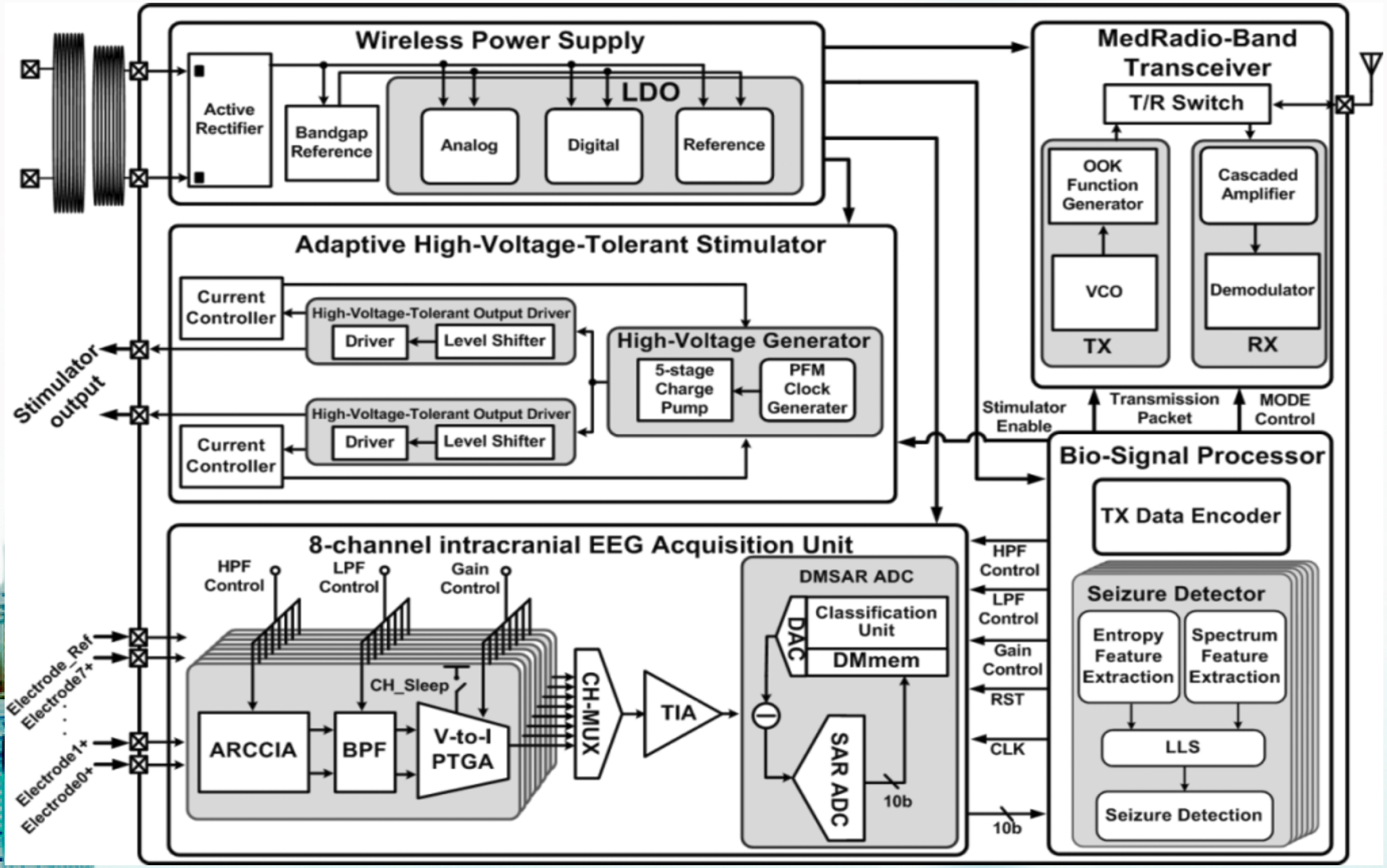
II. System Architecture and Design Considerations

B. Closed-loop implantable SoC for seizure control on Rate



[4] W. Chen, *et al.*, “A fully-integrated 8-channel closed-loop neural-prosthetic CMOS SoC for
real-time epileptic seizure control,” *IEEE J. Solid-State Circuits*, vol. 49, no. 1, pp. 232-247, Jan.
2014.

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II. System Architecture and Design Considerations

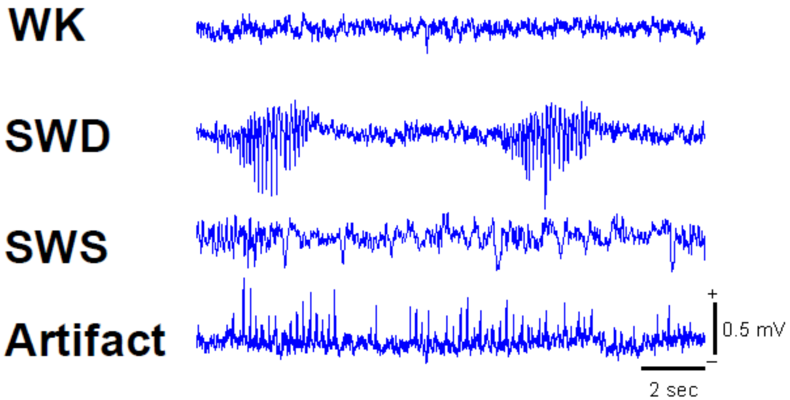
B. Closed-loop implantable SoC for seizure control on Rate

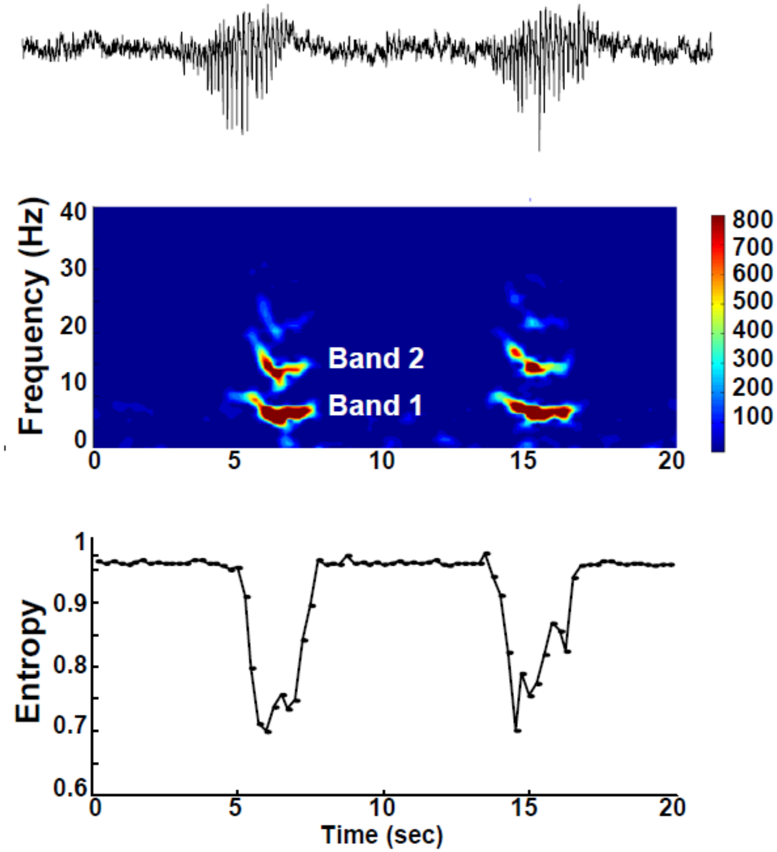
- The iEEG (ECoG) is sensed by a low-noise, low-power, and programmable gain pre-amp and digitized by a delta-modulated SAR ADC.
- The digitized iEEG are then processed by a specific algorithm for seizure detection in the bio-signal processor.
- Once the seizure is detected, the stimulator generates a fixed 30μA biphasic stimulation current to suppress the seizure onset.
- The wireless power and the MedRadio-band transceiver for bilateral data telemetry are implemented to extend device lifetime, to provide essential information for medical doctors., and to enable the control of implanted device from outside.

II. System Architecture and Design Considerations

B. Closed-loop implantable SoC for seizure control on Rate

Feature Extraction of Seizure Detection:





- Seizures
  - Spike wave discharges (SWD)
- Non-seizures
  - Wakefulness (WK)
  - Slow-wave sleep (SWS)
  - Artifact

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II. System Architecture and Design Considerations

B. Closed-loop implantable SoC for seizure control on Rate

Features of Brain Waves:

	Frequency band (Hz)	Entropy Detection Threshold
WK	No specific	1
SWD	7-11 (Band1) 15-18 (Band2)	0.7
SWS	0.4-4	0.85
Artifact	Random	0.9

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Outline

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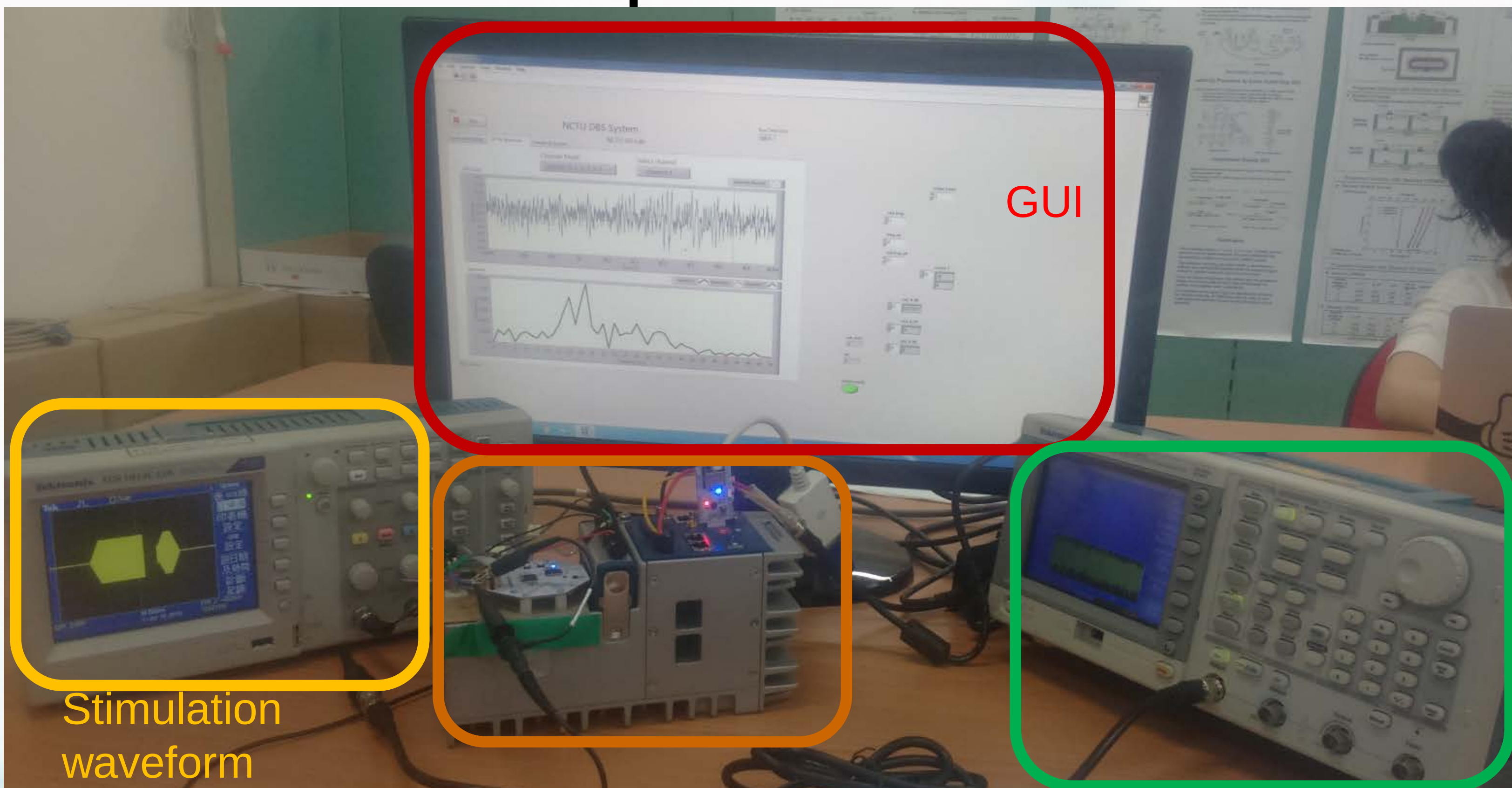
III. Experimental Results

A. Closed-loop PD DBS system for pre-implant Evaluation

❖ **Measurement setup**



Closed-loop PD DBS system

NI 9269 simulator

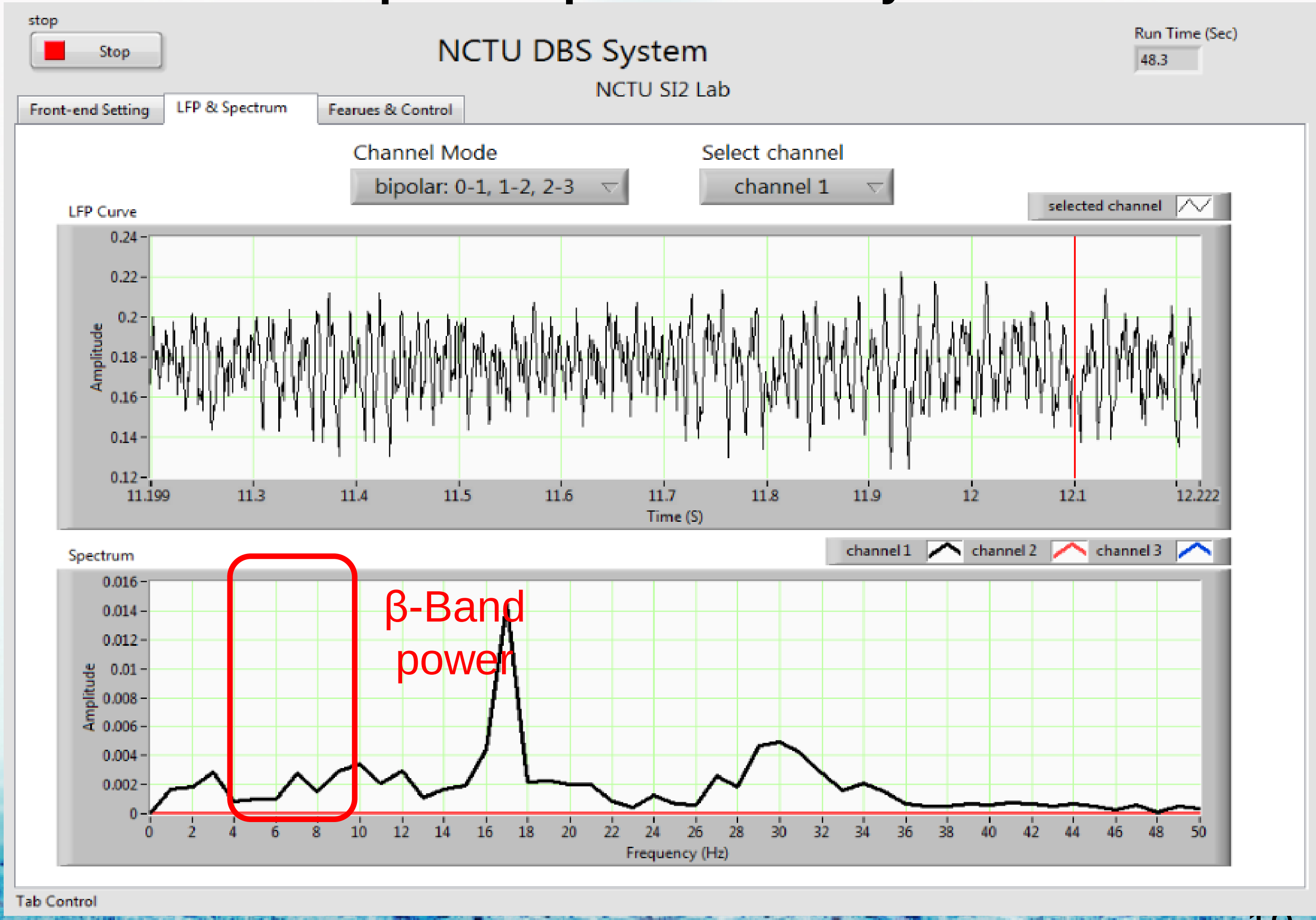
III. Experimental Results

A. Closed-loop PD DBS system for pre-implant Evaluation

❖ **Recorded LFP waveform and power spectral density**

Recorded LFP waveform

LFP power spectral density

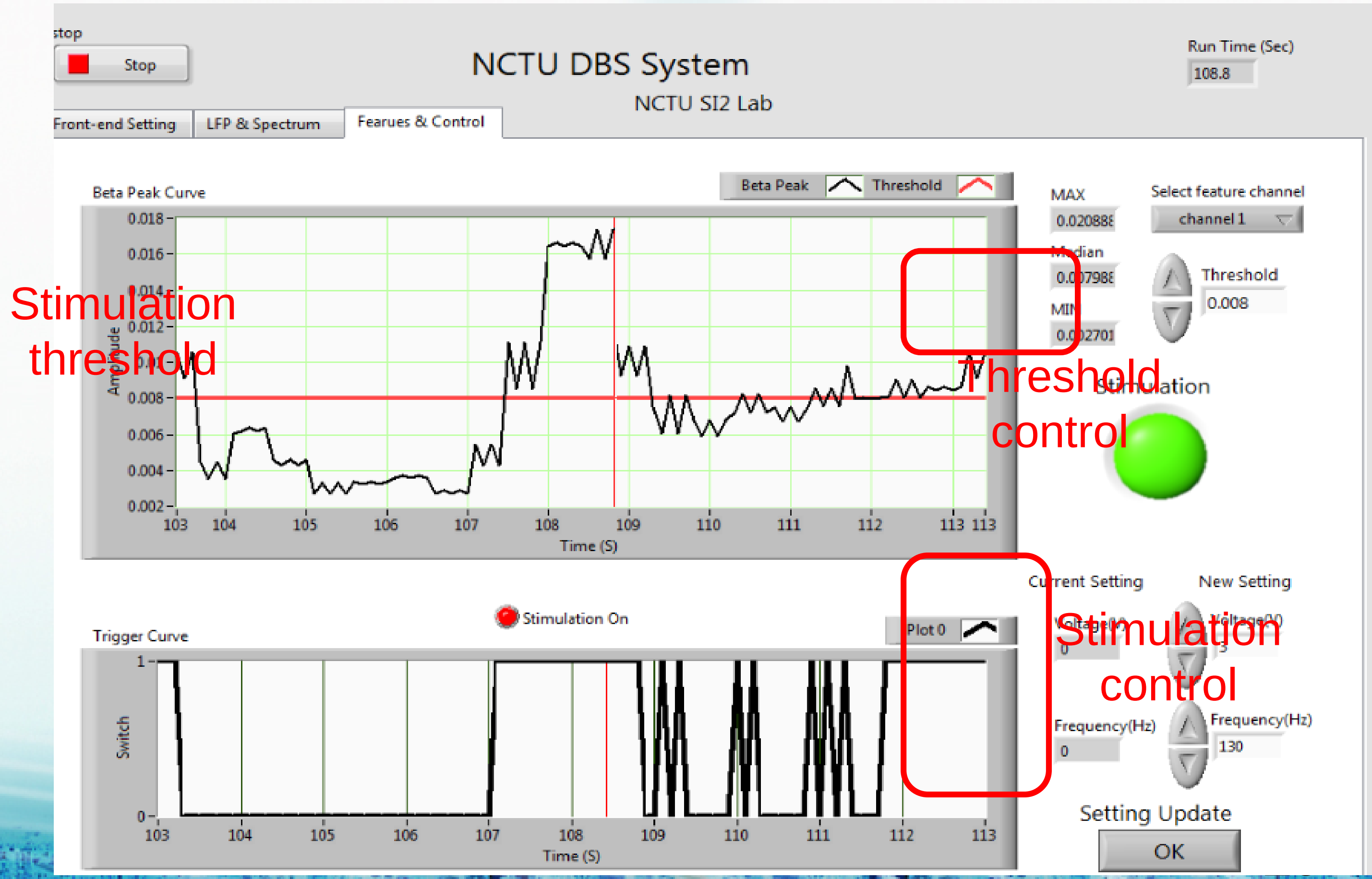


III. Experimental Results

A. Closed-loop PD DBS system for pre-implant Evaluation

- β-band power spectral density and stimulation control panel

Beta band power

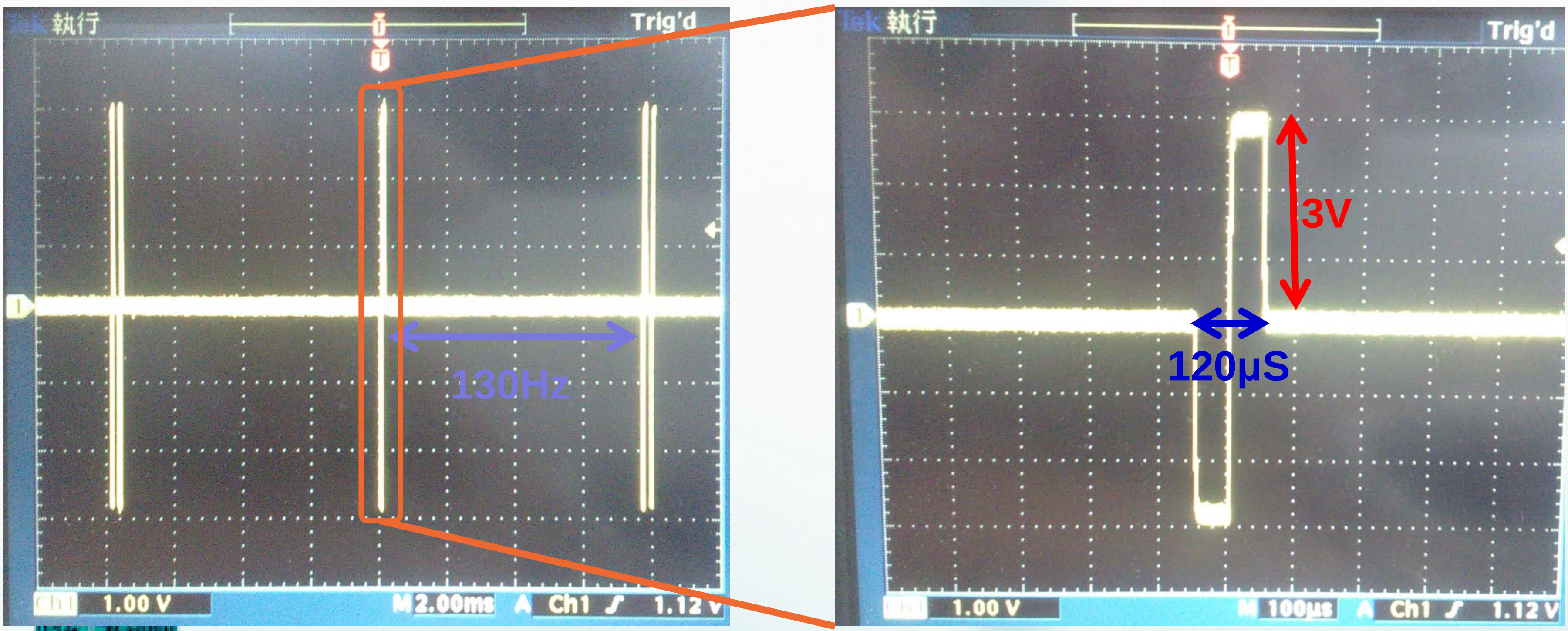


Stimulation control

III. Experimental Results

A. Closed-loop PD DBS system for pre-implant Evaluation

❖ **The biphasic constant-voltage stimulation waveforms**



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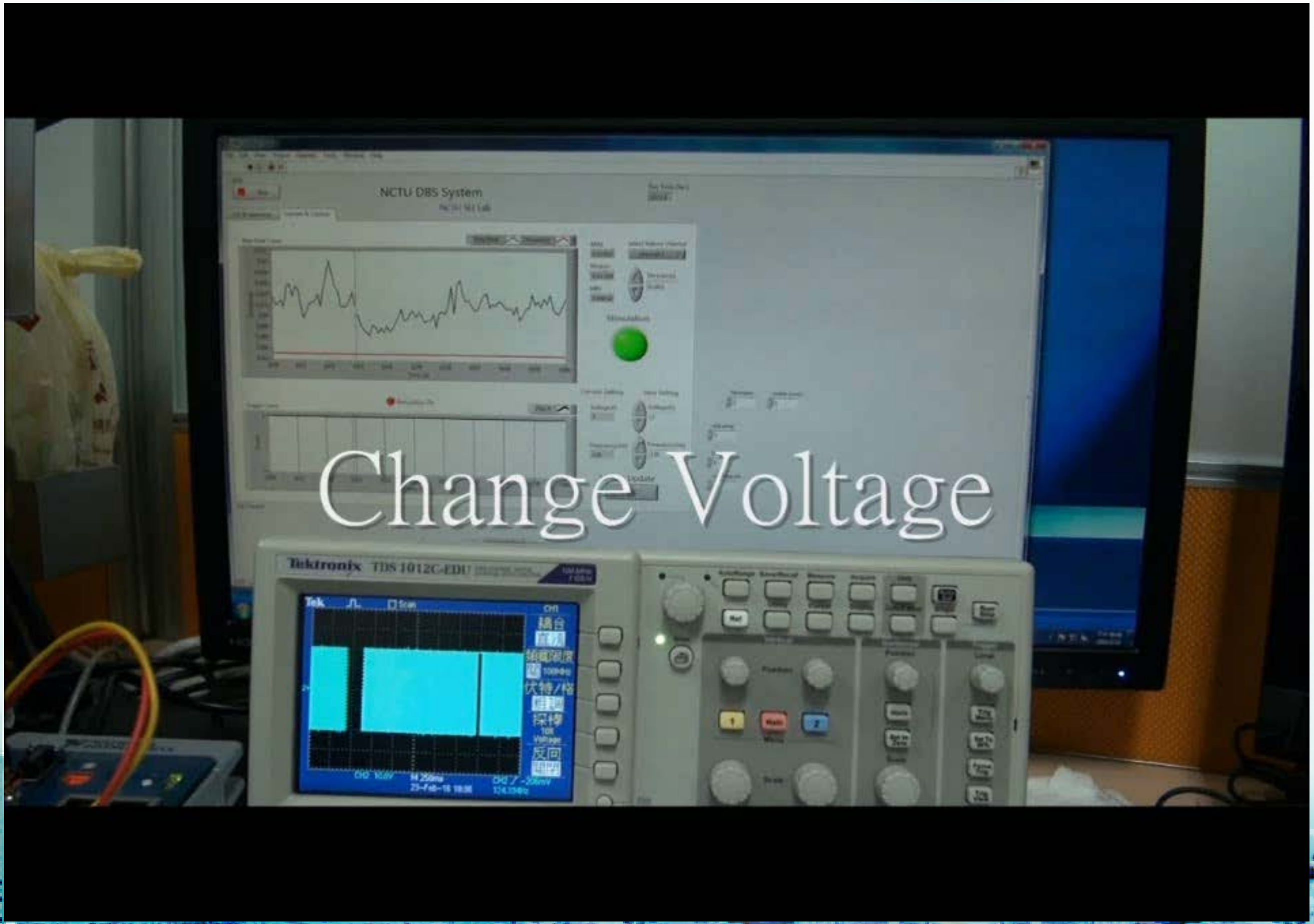
III. Experimental Results

A. Closed-loop PD DBS system for pre-implant Evaluation

❖ **Stimulator – changing voltage**



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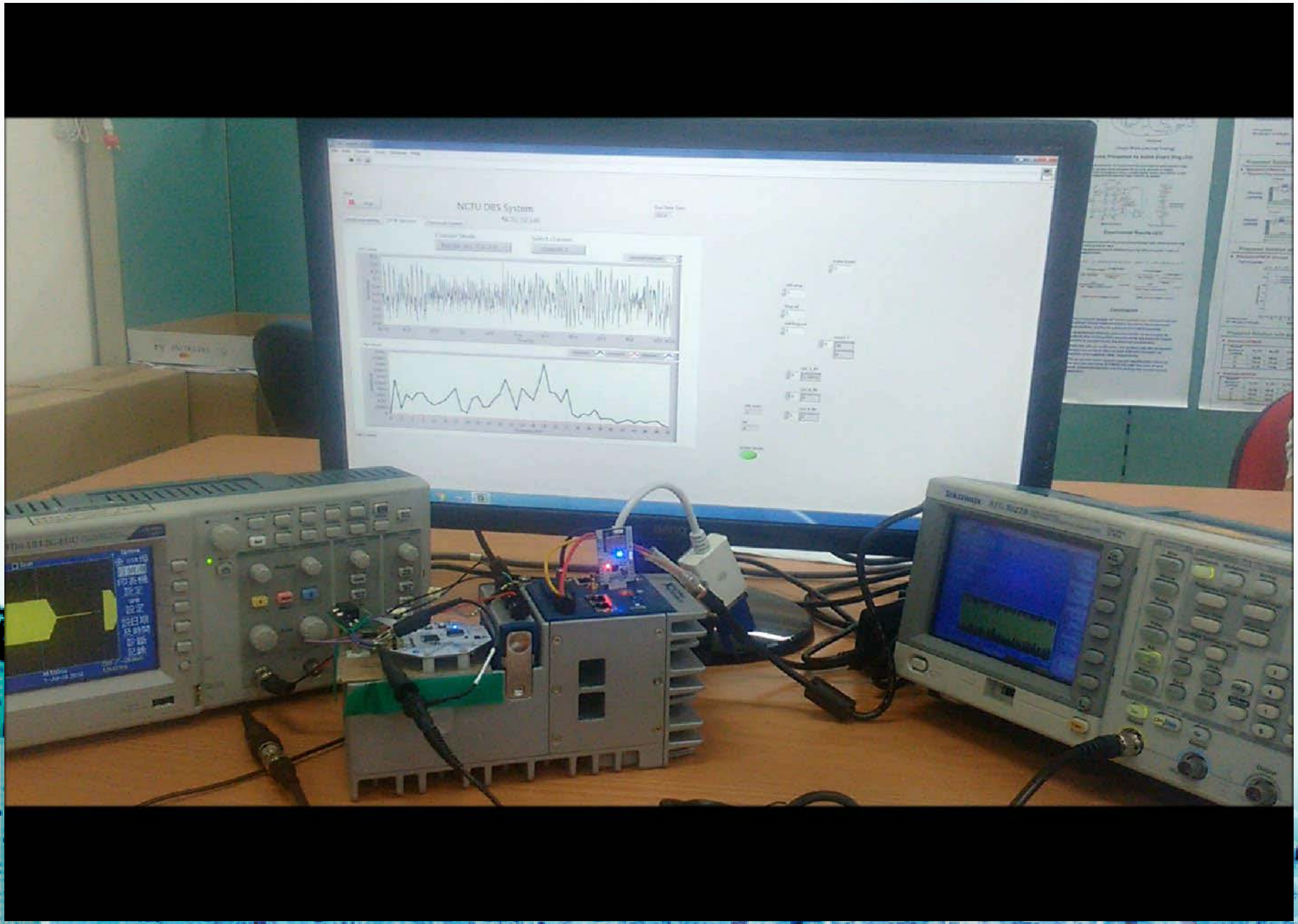
III. Experimental Results

A. Closed-loop PD DBS system for pre-implant Evaluation

- System demonstration – Closed-loop DBS



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III. Experimental Results

A. Closed-loop PD DBS system for pre-implant Evaluation

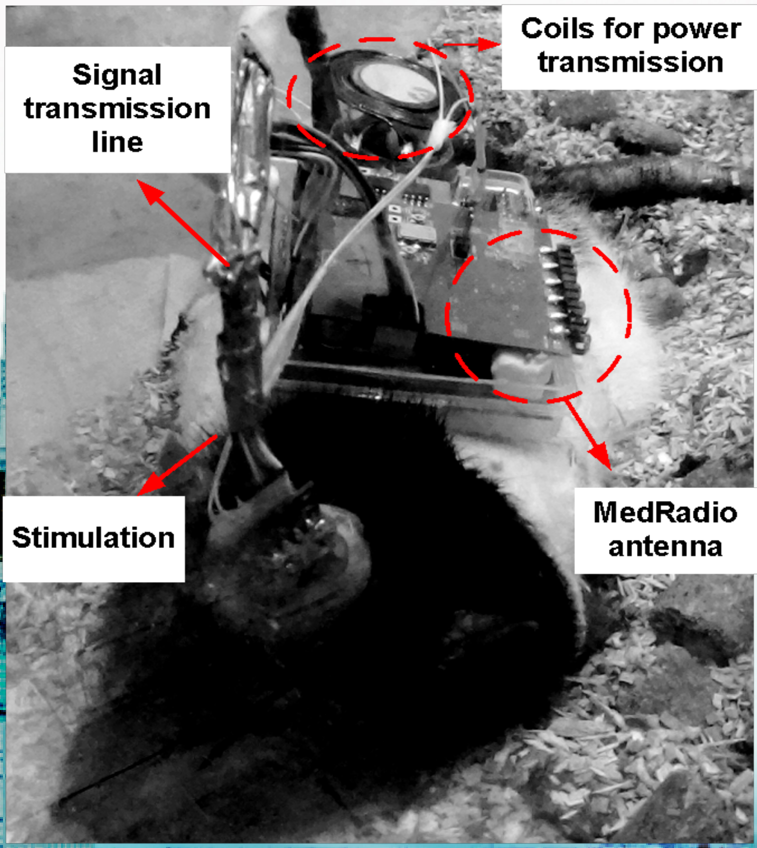
❖ **Performance summary**

	Parameters	Experimental results
LFP signal acquisition unit	Input common range	5V
	Input referred noise	1 μVpp
	CMRR	110dB
	ENOB	21.48
Biphasic constant voltage stimulator	Stimulation pulse width	60 μs
	Stimulation frequency	15-130Hz
	Stimulation voltage	0.1-3V

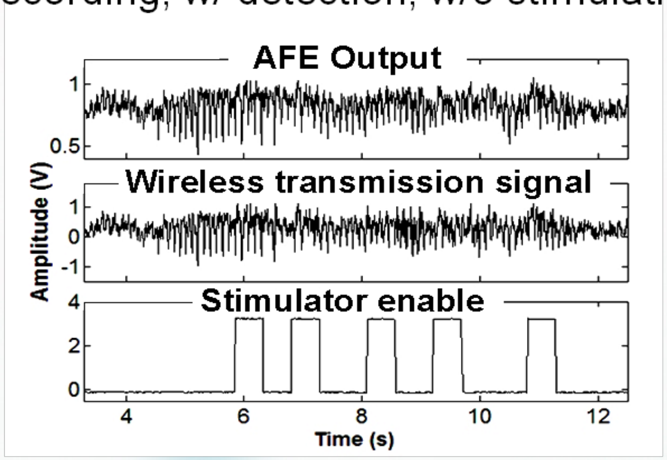
III. Experimental Results

B. Closed-loop implantable SoC for seizure control on Rate

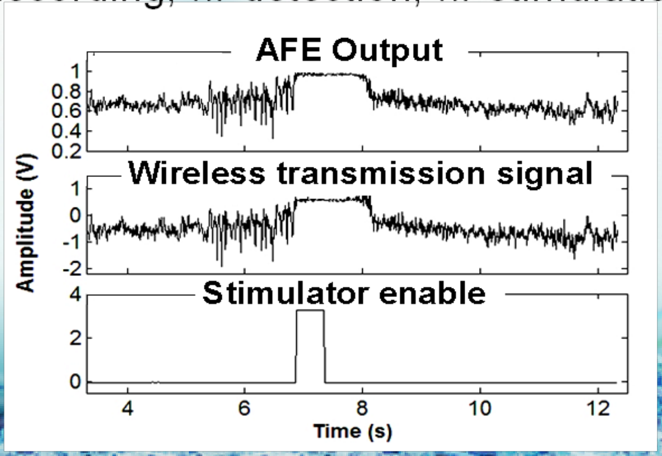
❖ **Animal Experiment :**



- Recording, w/ detection, w/o stimulation



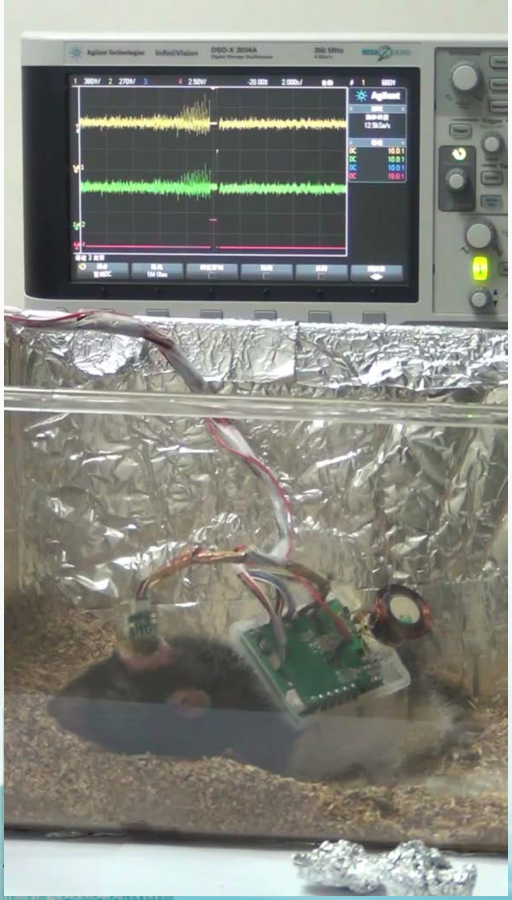
- Recording, w/ detection, w/ stimulation

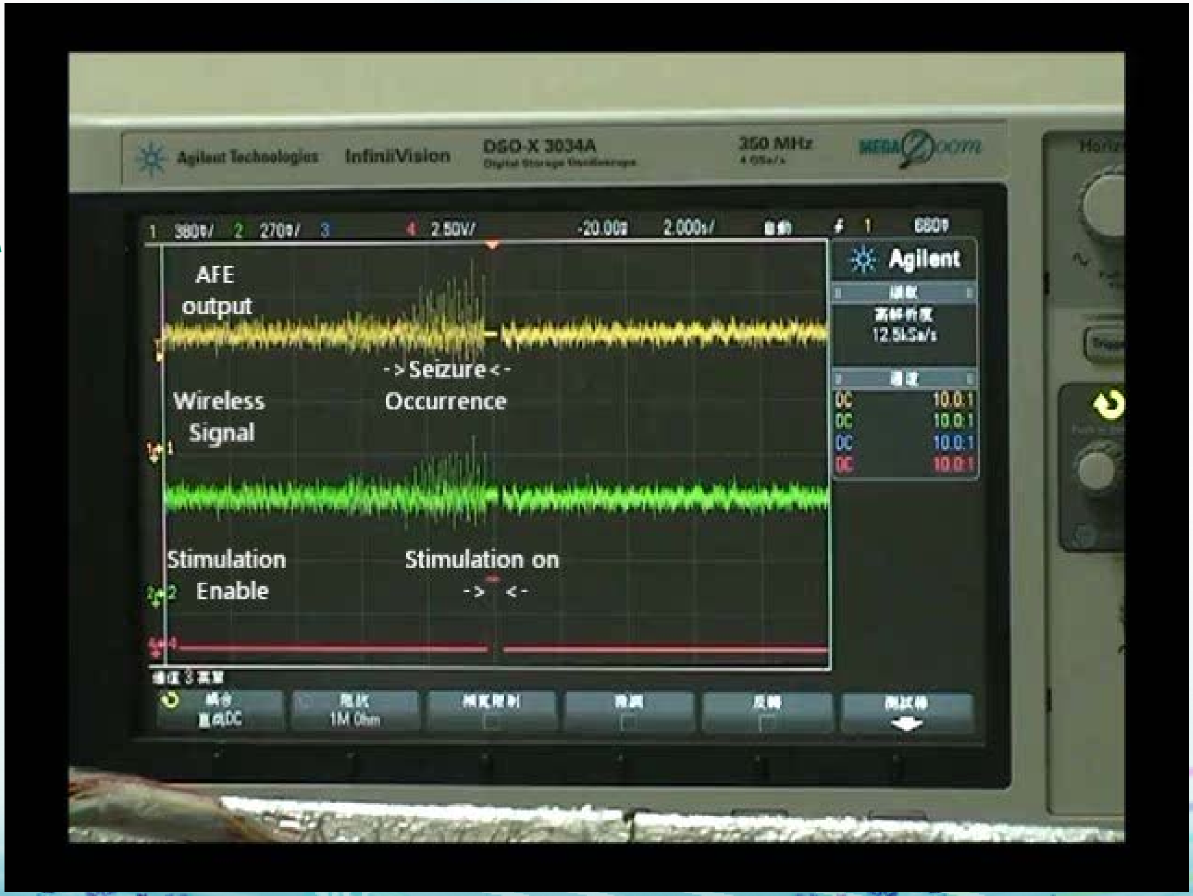


III Experimental Results

B. Closed-loop implantable SoC for seizure control on Rate

❖ **Acquisition, Detection & Stimulation:**





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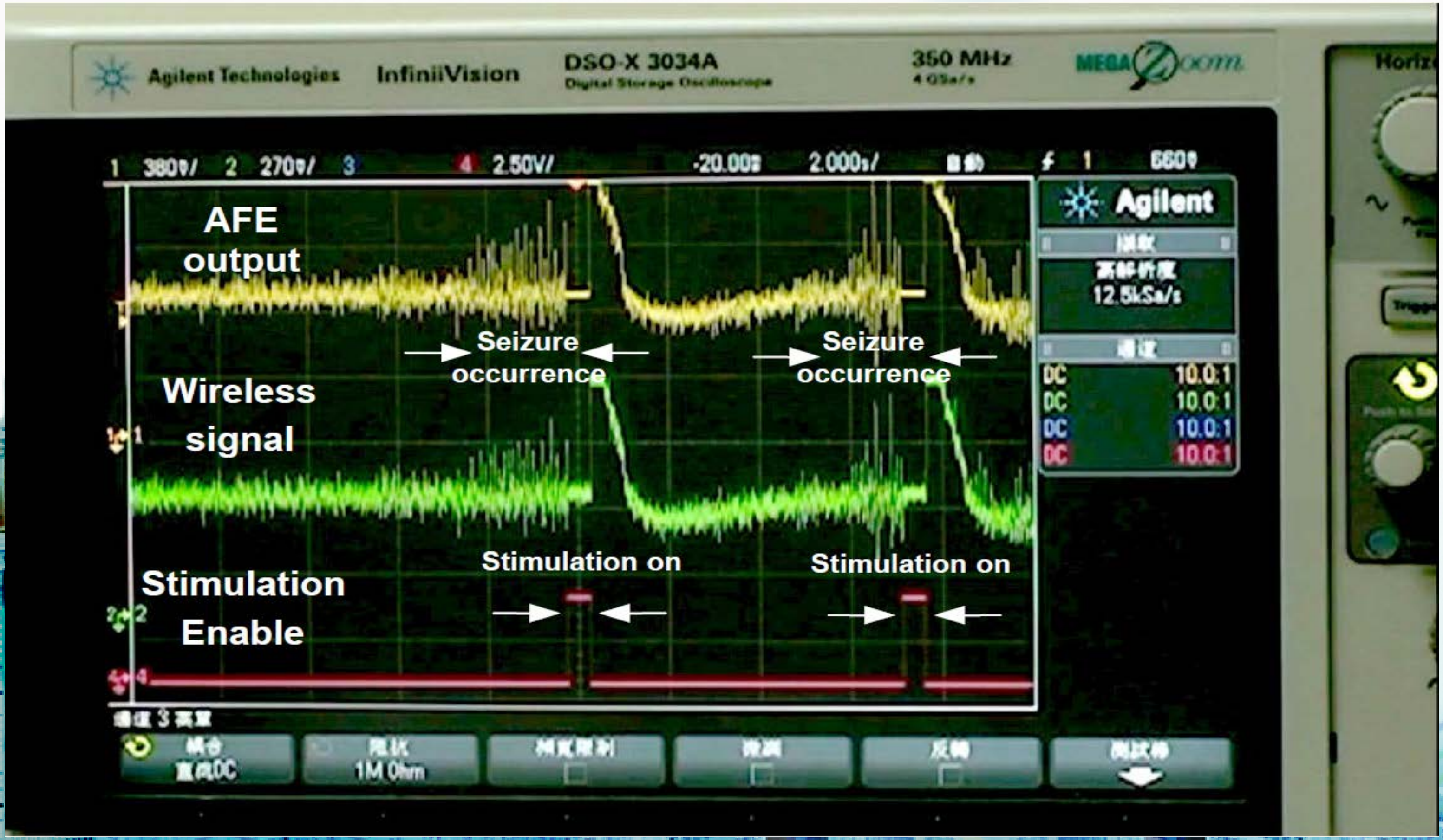
III. Experimental Results

B. Closed-loop implantable SoC for seizure control on Rate

❖ **Animal Experimental Results :**



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III. Experimental Results

B. Closed-loop implantable SoC for seizure control on Rate

❖ **Performance summary**

	Parameters	Experimental Results
Signal acquisition unit	Input-referred noise	5.23 μ Vrms
	NEF	1.77
Bio-signal processor	Accuracy	92%
	Latency	0.8s
Stimulator	Stimulation current	30 μ A
Wireless telemetry	Rectifier power conversion efficiency	84%
	Data rate	4M bps
	Total power consumption	2.8mW (stanby)

Outline

I. Introduction
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IV. Future Development

A. Closed-loop PD DBS system

- From the prototype of closed-loop PD DBS system for pre-implant evaluation to SOC
  - The pre-implant evaluation system will be used in clinical trial.
  - The measured data will be used to design the SOC for both pre-implant evaluation system and implantable system.
  - SoC is more power efficient with smaller area and it is suitable for implantable system.
  - The wireless power transmission is important to avoid frequent battery replacement.
  - The wireless power will be used to operate the SOC and charge the implantable rechargeable Li battery.
  - The wireless data telemetry is used to transmit LFP out and send commands in for medical doctors.

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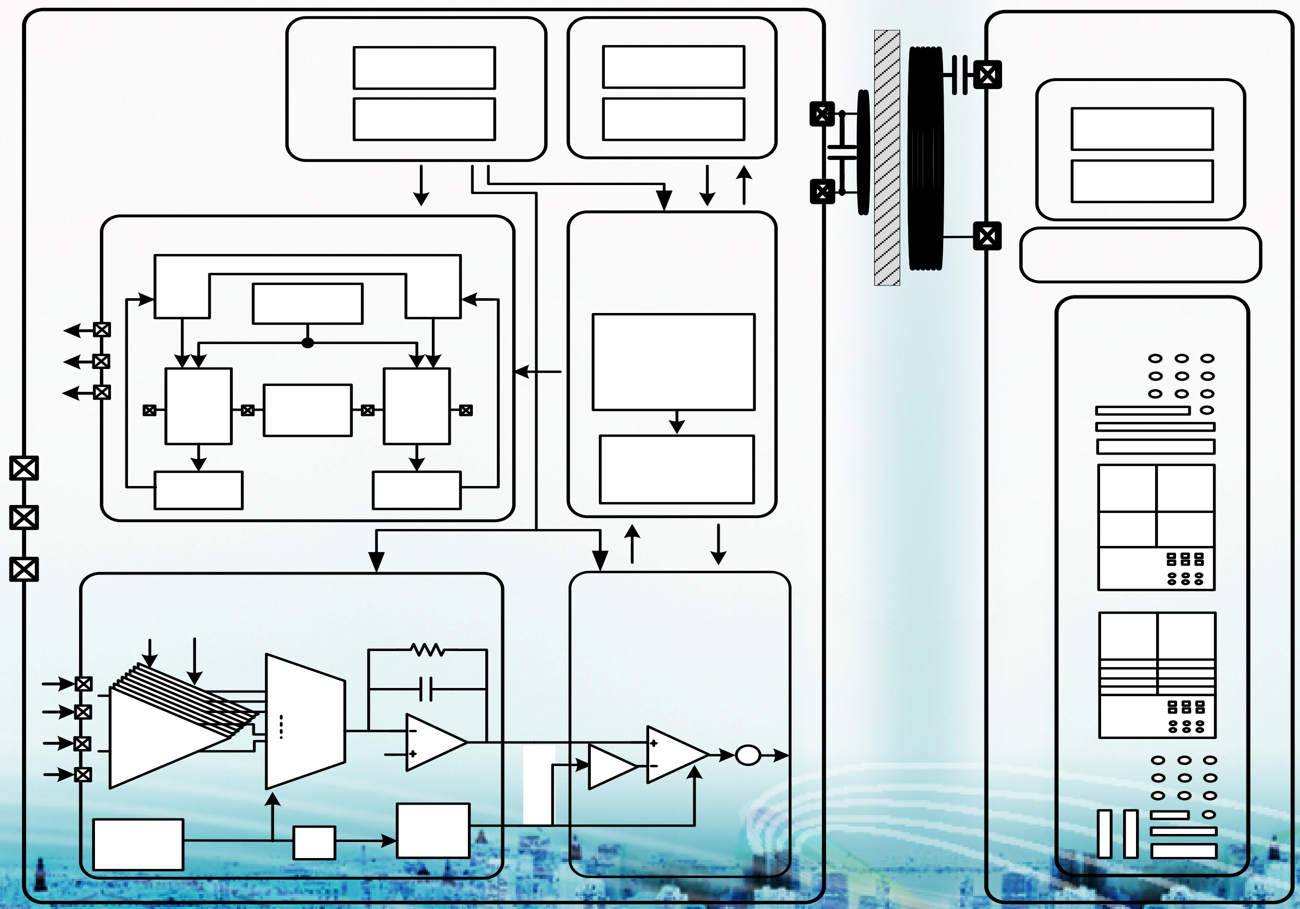
IV. Future Developemnt

A. Closed-loop PD DBS system

❖ System architecture of next generation closed-loop PD DBS SOC



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IV. Future Development

B. Closed-loop implantable SoC for seizure control

❖ **From animal test to clinical trial**

- Up to 3mA stimulation current on cortical surface is required to control human epileptic seizures.
- Channel number will also be increased to 16 to cover the human brain seizure onset sites.
- To reduce device area, only one pair of coil is developed for wireless power and bilateral data telemetry and rechargeable battery should be integrated in the implantable device.
- The designed closed-loop SOC for epileptic seizure control will be used in pre-implant brain evaluation/mapping system and implantable system.

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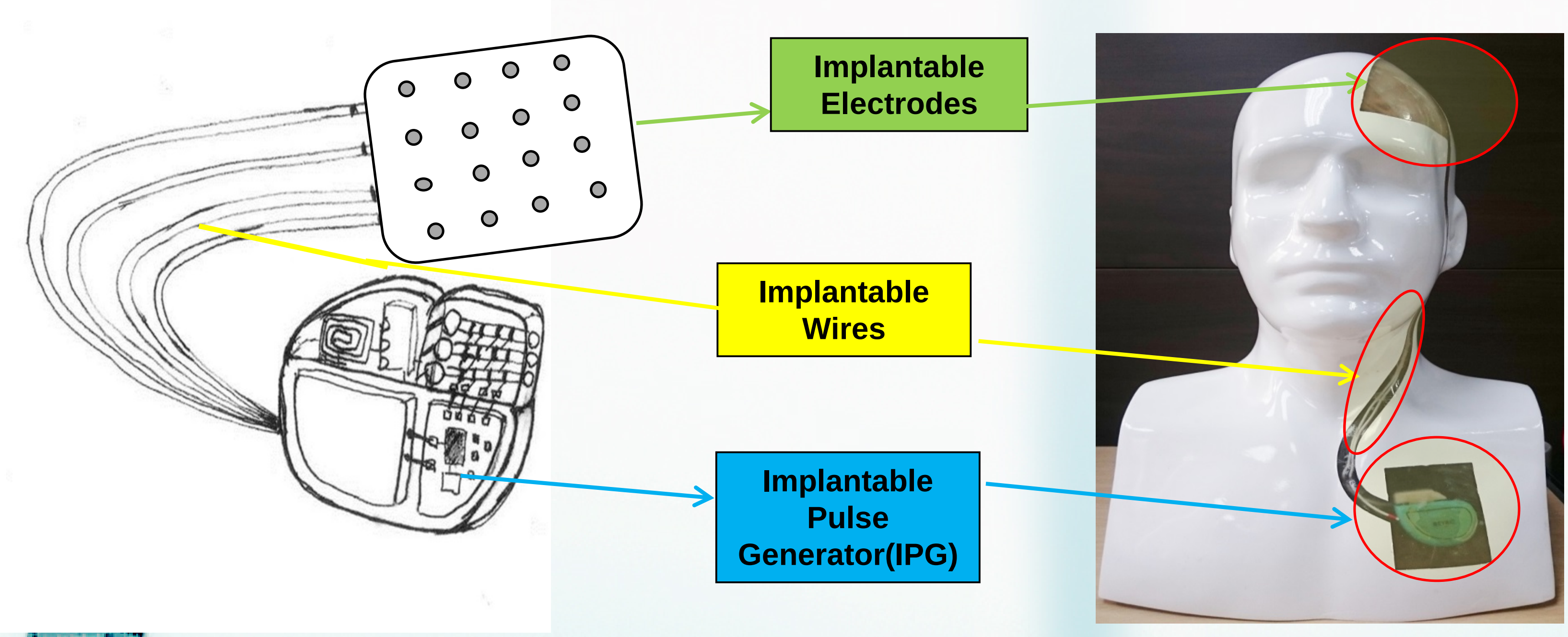
III. Future Development

B. Closed-loop implantable SoC for seizure control

❖ From animal test to clinical trial



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Thanks for your attention !

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